

UNCLASSIFIED

AD NUMBER

ADB026731

NEW LIMITATION CHANGE

TO

**Approved for public release, distribution
unlimited**

FROM

**Distribution authorized to U.S. Gov't.
agencies only; test and evaluation; Feb
1978. Other requests shall be referred to
Director, Chemical Systems Laboratory,
Attn: DRDAR-CLJ-R, Aberdeen Proving
Ground, Maryland 21010.**

AUTHORITY

USAARDC ltr, 9 Mar 1979

THIS PAGE IS UNCLASSIFIED

AD No.
DDC FILE COPY

ADB026731

57-1
AD-A 400 121

AD

(2)

CONTRACTOR REPORT ARCSL-CR-78003

PARAMETRIC STUDIES OF PYROTECHNIC MATERIALS BY BOMB CALORIMETRY

by

F. L. McIntyre
G. L. McKown

February 1978



NASA NATIONAL SPACE TECHNOLOGY LABORATORIES
Computer Sciences Corporation
Engineering and Science Services Laboratory
NSTL Station, Mississippi 39529

Contract No. NAS13-50



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010

Distribution limited to US Government agencies only because of test and evaluation; February 1978. Other requests for this document must be referred to Director Chemical Systems Laboratory, Attn: DRDAR-CLJ-R, Aberdeen Proving Ground, MD 21010.

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

(18) ARCSL, SP12 / 17/CR-78003 H-49712

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARCSL-CR-78003	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
6. PARAMETRIC STUDIES OF PYROTECHNIC MATERIALS BY BOMB CALORIMETRY.		9. TYPE OF REPORT & COMM COVERED Final Test Feb. 1976 - Apr. 1977
7. AUTHOR(s) F. L. McIntyre G. L. McKown		15. CONTRACT OR GRANT NUMBER(s) NAS13-50 MIPR 8166104601F4W5
8. PERFORMING ORGANIZATION NAME AND ADDRESS NASA National Space Technology Laboratories Computer Sciences Corporation Engineering and Science Services Laboratory NSTL Station, Mississippi 39529		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PEMA Project 5761313
11. CONTROLLING OFFICE NAME AND ADDRESS Director, Chemical Systems Laboratory Attn: DRDAR-CLJ-R Aberdeen Proving Ground, MD 21010		12. REPORT DATE Feb. 1978
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Director Chemical Systems Laboratory Attn: DRDAR-CLN-S Aberdeen Proving Ground, MD 21010 (CPO: R. Belmonte 671-3402)		13. NUMBER OF PAGES 14 (12) 12P. 1
16. DISTRIBUTION STATEMENT (of this Report) Distribution limited to U.S. Government agencies only because of test and evaluation; February 1978. Other requests for this document must be referred to Director Chemical Systems Laboratory, Attn: DRDAR-CLJ-R, Aberdeen Proving Ground, Maryland 21010.		15. SECURITY CLASS. (or information) UNCLASSIFIED
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Calorimetry Pyrotechnics Colored Smoke Mixes		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A series of tests were performed in a large bomb calorimeter using four sulfur-based colored-smoke compositions. It was found that (1) energy output increases with decreasing sample density, (2) violet smoke is more energetic than the other colored-smoke mixes, and (3) the energy output increases significantly with increased ambient pressure.		

PREFACE

The investigation described in this report was authorized under MIPR 8166104601F4W5, Project 5761313. This work was performed at the NASA National Space Technology Laboratories (NSTL) under the direction of the ARRADCOM Resident Operations Officer through NASA by the Computer Sciences Corporation as the support contractor. The experimental work was completed April 1977. (It was started in February 1976.)

Reproduction of this document in whole or in part is prohibited except with permission of the Director, Chemical Systems Laboratory, Attn: DRSAR-CLJ-R, Aberdeen Proving Ground, Maryland, 21010; however, DDC is authorized to reproduce the document for United States Government purposes.

The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software. This report may not be cited for purposes of advertisement.

The information in this document has not been cleared for release to the general public.

ACCESSION for		
NTIS	White Section <input type="checkbox"/>	
DDC	Buff Section <input checked="" type="checkbox"/>	
UNANNOUNCED <input type="checkbox"/>		
JUSTIFICATION		
BY		
DISTRIBUTION/AVAILABILITY CASES		
Dist.	A B B	C SPECIAL

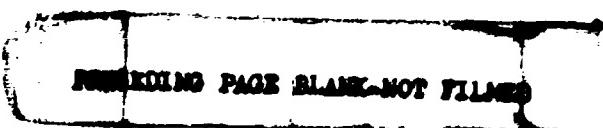


TABLE OF CONTENTS

	<u>PAGE</u>
1.0 INTRODUCTION	7
1.1 Objective	7
1.2 Authority	7
1.3 Background	7
2.0 EXPERIMENTAL METHODS	7
2.1 Test Configuration	7
2.2 Test Method	7
2.3 Instrumentation	8
2.4 Pressure Effects	8
3.0 TEST RESULTS AND DISCUSSION	8
3.1 Material Consolidation	8
3.2 Dye Effects	10
3.3 Effects of Initial Pressure	11
4.0 CONCLUSIONS	11
5.0 RECOMMENDATIONS	11
DISTRIBUTION LIST	13

LIST OF TABLES

<u>TABLE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
1	Effects of Consolidation on the Reaction of Violet Smoke Mix IV.	10
2	Effects of Dyes on the Reaction Rate of Colored Smoke Compositions.	11
3	The Effects of Initial Pressure on 50-Gram Samples of Violet Smoke Mix IV	12

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

<u>FIGURE</u>			<u>PAGE</u>
<u>NO.</u>	<u>TITLE</u>		
1	Bomb Calorimetry Test Apparatus		8
2	Electrical Wiring Diagram of Thermocouple and Pressure Transducer Hookup		9
3	Effects of Initial Pressure versus Heat of Reaction		12

PARAMETRIC STUDIES OF PYROTECHNIC MATERIALS BY BOMB CALORIMETRY

1.0 INTRODUCTION

1.1 Objective. The objective of this study was to determine the effects of 1) material consolidation, 2) dye collant and 3) initial pressure on the burning rate and energy output of pyrotechnic compositions.

1.2 Authority. The work described in this report was authorized by MIPR 8166104601F4W5 from Edgewood Arsenal to the National Space Technology Laboratories.

1.3 Background. One of the important criteria used for measuring combustion performance of a pyrotechnic composition is the chemical energy released in the form of heat. A preliminary study of the performance of a pyrotechnic composition in a large-scale calorimeter was performed under project No. 5754099. The results obtained from those experiments indicated that heat transfer due to convection and radiation significantly affected the accuracy of the experiment, but that a large-scale-type bomb calorimeter was feasible for predicting the combustion performance of a pyrotechnic composition. This study also indicated that a similar type of calorimeter vessel which would reduce the heat loss from radiation and convection might be developed. A study was undertaken to develop such a vessel. Based upon this study, testing was performed in the proposed apparatus using four different sulfur-based colored smoke mixes.

2.0 EXPERIMENTAL METHODS

2.1 Test Configuration. The apparatus used in this experiment is shown in figure 1. The reaction vessel is a cylindrical steel tank with an internal volume of 0.024 m^3 and a wall thickness of 0.076 cm providing a total system heat capacity of 310 calories/ $^\circ\text{K}$ at one atmosphere pressure. The tank is surrounded by four layers of 2.5 cm foil-backed fiberglass insulation.

2.2 Test Method. The experiments were performed using violet, red, green, and yellow smoke mixtures. These mixtures were pressed at Edgewood Arsenal to specified densities approximating first, second, third and fourth increment pressings typical of those used in the manufacturing of smoke grenades. Violet Smoke Mix IV, drawing No. B143-5-1 was pressed to densities of 1.16, 1.32, 1.48 and 1.61 grams per cubic centimeter. Each pellet was 5 cm (2 inches) in diameter and varied in height from 1.75 cm (11/16 inches) to 2.4 cm (15/16 inches) depending upon the pressed density. Weights varied from 53.1 grams to 50.5 grams with an average weight of 51.9 grams. The samples were used to measure the effect of consolidation upon the reaction rate of smoke mixtures.

Yellow, red, and green sulfur based smoke mixes were pressed into pellets of 1.33, 1.46, and 1.30 grams per cubic centimeter with average weights of 51.3, 54.2 and 52.3 grams respectively. These samples were used to determine the effect of specific dyes upon the reaction rate of the mixtures.

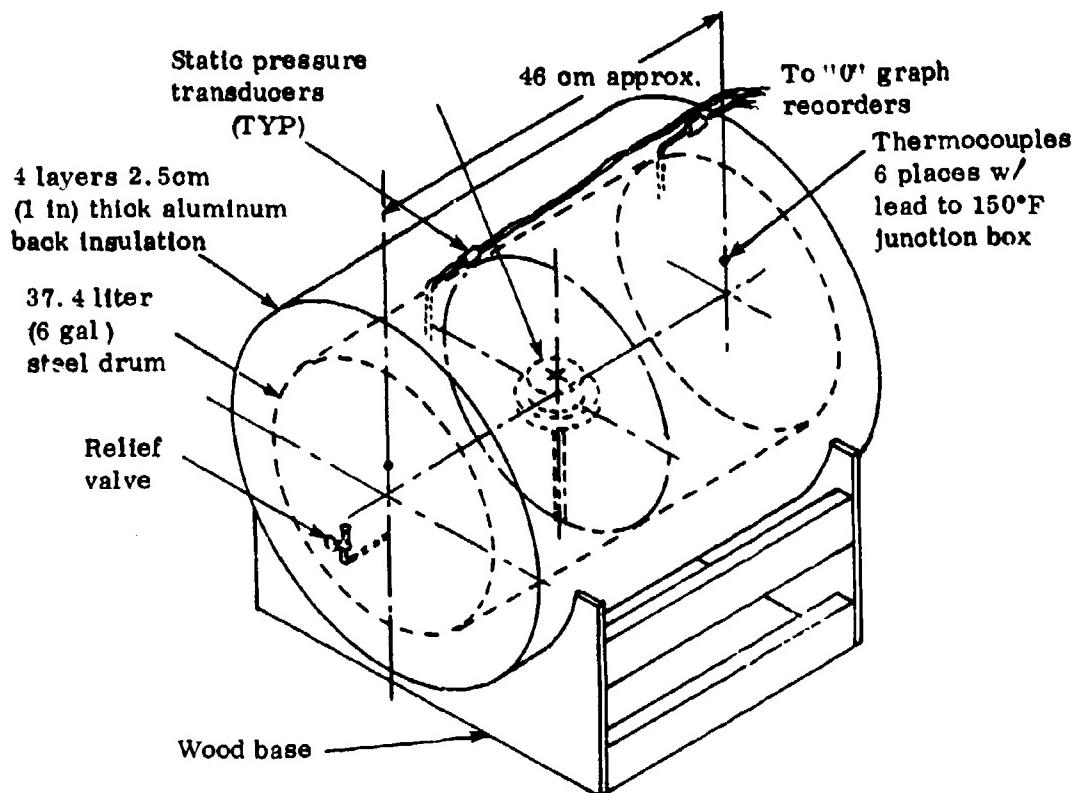


Figure 1. Bomb Calorimetry Test Apparatus

2.3 Instrumentation. Six chromel/alumel thermocouples were placed on the container. Four of the thermocouples were placed at 90° angles on the vessel wall 22.9 cm (8 inches) from the front of the vessel, and one each thermocouple was placed in the center of each end wall of the vessel. The thermocouples were connected to a Pace Model BRJW13A-24TT-1517 thermocouple reference junction then connected to underground cabling which led to the test control center (TCC) where the signals were recorded on a Honeywell Model 1612 Visicorder Oscillograph operated at 2.5 cm/sec (1 inch/sec). Two strain-gauge-type pressure transducers (BLH Model 151-HAC-134, 0 to 138 kilopascal [0-20 psi] full-pressure response) were mounted on each end of the vessel and connected to underground cabling to two Dynamic Model 6457 DC Amplifiers, each connected to the same oscilloscope recorder. Figure 2 shows schematically the instrumentation setup.

2.4 Pressure Effects. The experiments on effect of initial pressure were performed in an early model of the calorimeter which used a thin metal liner within a larger cylindrical tank. Since in this version the sample holder was more massive and not directly connected to the liner, both sample holder and liner temperatures were included in the calculation of heat of reaction. Temperature and pressure were measured in the same manner as described previously. Due to the design of this calorimeter it was not possible to unambiguously evaluate the pressure rise rate, from which reaction rate is inferred.

3.0 TEST RESULTS AND DISCUSSION

3.1 Material Consolidation. Results of the tests to evaluate the effects of consolidation on the burning rate and energy output of violet smoke mix are shown in table 1. The total

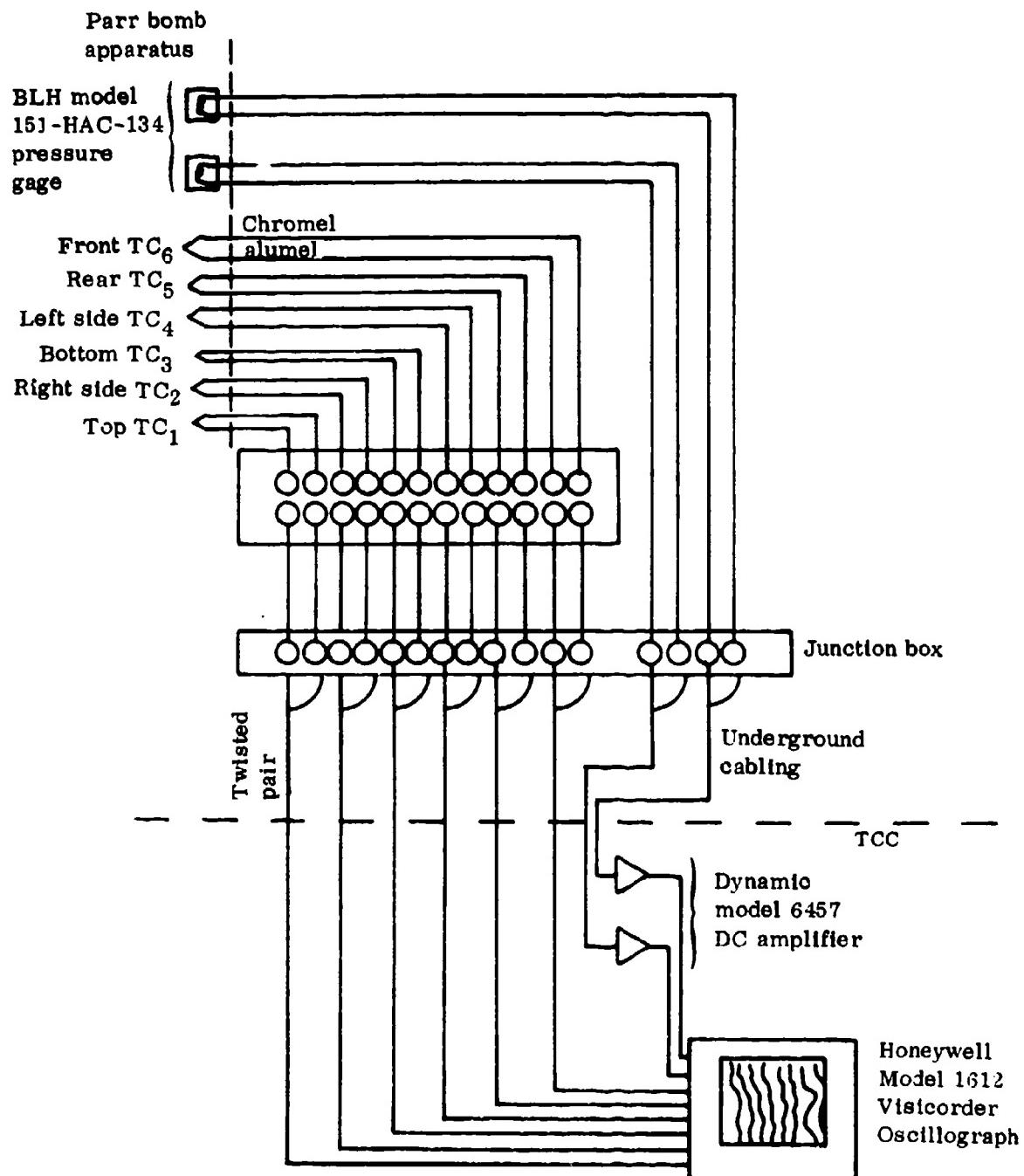


Figure 2. Electrical Wiring Diagram of Thermocouple and Pressure Transducer Hookup

Table 1. EFFECTS OF CONSOLIDATION ON THE REACTION OF VIOLET SMOKE MIX IV

Weight in grams	Pressed density gm/cc	Total pressure kpascal	Time at		Rate of pressure rise kpascal/sec	Heat of reaction cal/gm	Temperature		
			T ₁ sec	P _{max} sec			T ₁ °C	T _{max} °C	ΔT °C
53.1	1.18	137.9	3.6	10.0	21.5	1054	15.6	152.8	137.2
51.7	1.15	117.2	4.0	15.0	10.7	465	26.7	78.9	52.2
52.4	1.16	110.3	4.0	15.0	10.0	779	54.4	147.2	92.7
51.5	1.33	86.2	6.5	29.1	3.8	923	14.4	123.3	108.9
50.5	1.30	86.2	7.0	23.8	5.1	922	30.6	137.2	106.7
51.2	1.33	82.7	6.6	27.4	4.0	779	41.1	132.2	91.1
52.2	1.48	78.3	8.1	34.3	3.0	776	12.2	105.0	92.8
53.0	1.49	75.8	8.0	31.6	3.2	603	23.3	96.1	72.8
51.5	1.46	82.7	7.7	33.5	3.2	650	39.4	115.6	76.2
51.3	1.59	72.4	8.6	38.2	2.4	646	-11.1	64.4	75.6
53.1	1.65	86.2	8.0	36.0	3.1	676	12.8	94.4	81.7
51.3	1.59	87.6	7.4	33.3	3.4	824	8.9	105.6	96.7

pressure developed within the chamber varied from 122 kPa to 79 kPa for samples with average densities of 1.16 gm/cm³ to 1.61 gm/cm³, respectively. A slight, albeit significant increase in pressure was observed for increasing material density at the higher end of the density range. If the data point showing a minus 11.1°C initial temperature is discarded, the resultant pressure increase in this density range is about 8 kPa. In general; however, the total developed pressure decreased with increasing sample density. The time required to develop maximum pressure was proportional to density and varied from a minimum of approximately 14 seconds for a density of 1.16 gm/cm³ to 36 seconds for a density of 1.61 gm/cm³. The rate of pressure rise varied from a maximum rate of 14 kPa/sec for a density of 1.16 gm/cm³ to a minimum of 3 kPa/sec for a density of 1.61 gm/cm³, the effect of the pressure rate of rise thus varies directly with sample density. Heat of reaction varied from a maximum of 1054 cal/gm for a density of 1.16 gm/cm³ to a minimum of 465 cal/gm at the same density but the overall trend indicated that heat of combustion was inversely proportional to density. Temperature also varied inversely as a function of density.

3.2 Dye Effects. Table 2 shows the tabulated results of the cooling effect of the dye in pyrotechnic compositions on the reaction rate and output energy. Total pressure was less for the green, red and yellow smoke mixes than that recorded for the violet smoke at nearly the same densities. Time to maximum pressure was also longer for the other dye materials versus violet smoke; therefore, the pressure rate of rise was less for the other colored smokes. Heat of reaction was also less for the green, red and yellow smoke mixes than the violet smoke mix at similar densities. In all measured aspects, the energy output from the red, green and yellow smoke mixes were less than that for the violet smoke at similar densities.

Table 2. EFFECTS OF DYES ON THE REACTION RATE OF COLORED SMOKE COMPOSITIONS

Sample material	Weight in grams	Pressed density gm/cc	Total pressure kpeson	Time		Rate of pressure rise kpascoal/sec	Heat of reaction koal/gm	Temperature		
				Pt sec	Pmax sec			T ₁ °C	T _{max} °C	Δ T °C
Green smoke	52.2	1.30	72.4	8.4	40.2	2.3	476	37.8	93.3	55.6
	52.9	1.32	84.1	8.3	40.0	2.7	787	43.3	137.8	94.4
	52.7	1.31	86.2	6.1	39.4	2.6	769	51.7	143.3	91.7
	51.5	1.28	89.6	6.3	28.4	3.9	672	51.7	129.4	77.8
Yellow smoke	51.6	1.33								
	49.3	1.28								
	52.5	1.36	74.5	11.2	40.0	2.6	746	43.3	121.1	77.8
	51.9	1.34	64.1	11.0	50.0	1.6	637	37.8	112.8	75.0
Red smoke	53.8	1.45	84.8	9.7	26.1	4.8	881	45.1	152.8	107.8
	53.9	1.46	72.4	10.9	50.0	4.1	991	37.8	160.0	122.2
	54.9	1.48	72.4	5.9	45.0	4.1	973	37.8	160.0	122.2
	54.1	1.46	82.7	9.9	42.5	4.7	1047	37.8	167.2	129.4

3.3 Effects of Initial Pressure. The effects of initial pressure in the calorimeter on heat of reaction are tabulated in table 3 and presented graphically in figure 3. This work was conducted in the original calorimeter configuration using a metal liner inside a larger bomb. The results show that the heat of reaction changes by 40 percent when ambient pressure changes by 69 kilopascal (10 psi). These changes are on an order of magnitude greater than predictions based on thermodynamic consideration, and must be attributed to reaction of the dye or of the dextrin impurities in the smoke mix. Calculations show that the observed heat of reaction can be obtained if less than 10 percent of the dye is oxidized.

4.0 CONCLUSIONS

- (1) The heat of reaction for the combustion of Violet Smoke Mix IV is inversely proportional to its consolidation density.
- (2) The burning rate of Violet Smoke Mix IV is inversely proportional to the consolidation density.
- (3) A moderate change in ambient pressure has a marked effect on the energy output of the violet smoke reaction.
- (4) In all measured aspects, the energy output from the red, green and yellow smoke mixes were less than that for violet smoke at similar densities.

5.0 RECOMMENDATIONS

The results obtained in these experiments do not agree well with previous testing in a laboratory Parr Bomb apparatus.* Although these experiments were cursory in nature and only

*King, P. V. and D. M. Koger, Edgewood Arsenal Contractor Report No. GE-MTSD-R-059 Final Report, Pyrotechnic Hazards Classification and Evaluation Program Phase III Segments 1-4, Investigation of Sensitivity Test Methods and Procedures for Pyrotechnic Hazards Evaluation and Classification, April 1971.

a small number of tests were performed, the apparatus used in these experiments met expectations as a calorimetric measuring device. Additional experiments with the vessel would be required to standardize the procedure and an analysis technique.

Table 3. THE EFFECTS OF INITIAL PRESSURE ON 50-GRAM SAMPLES OF VIOLET SMOKE MIX IV

Initial pressure kilopascals (psi)	P kilopascals (psi)	Sample holder $\Delta T^\circ C$ ($^\circ F$)	Liner $\Delta T^\circ C$ ($^\circ F$)	Heat of reaction calories/gram
101.4 (14.7)	44.1 (6.4)	43.7 (110.7)	24.3 (75.8)	560
118.6 (17.2)	47.6 (6.9)	46.9 (116.4)	27.9 (82.2)	624
132.4 (19.2)	51.7 (7.5)	54.5 (130.1)	32.9 (91.2)	700
151 (21.9)	60.7 (8.8)	53.1 (127.6)	35.6 (96)	743
170.3 (24.7)	53.1 (7.7)	54.2 (129.5)	37.3 (99.2)	776

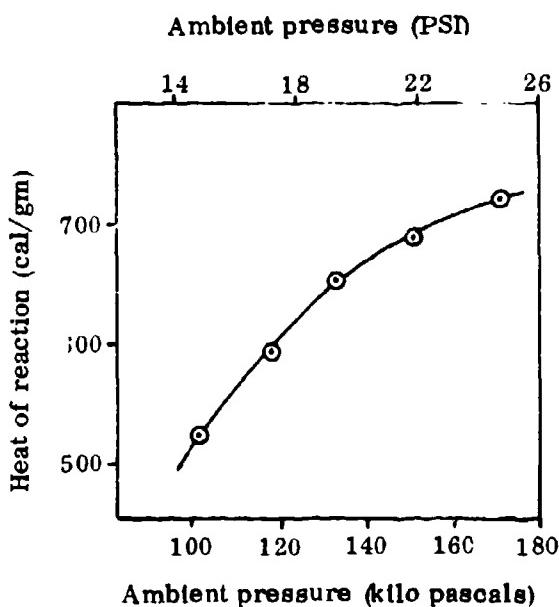


Figure 3. Effects of Initial Pressure versus Heat of Reaction

**PYROTECHNIC HAZARDS REPORTS
DISTRIBUTION LIST**

<u>Addressee</u>	<u>No. of Copies</u>
Commander US Army Armament Research and Development Command Attn: DRDAR-LCM Dover, NJ 07801	1
Commander Pine Bluff Arsenal Attn: Safety Office Engineering and Technology Pine Bluff, AR 71601	1 1
Commander Frankford Arsenal Attn: Safety Office Bridge and Tacony Streets Philadelphia, PA 19137	1
Commander Rocky Mountain Arsenal Attn: Safety Office Denver, CO 80240	1
Director National Aeronautics and Space Administration Attn: Safety Office Washington, DC 20546	1
Director NASA National Space Technology Laboratories Attn: Safety Office Bay St. Louis, MS 39529	1
Chairman Department of Defense Explosives Safety Board Forrestal Building, GB-270 Washington, DC 20314	1
Commander US Army Materiel Development and Readiness Command Attn: Safety Office 5001 Eisenhower Avenue Alexandria, VA 22333	2

**Project Manager, Munitions Production Base
Modernization and Expansion**

Attn: DRCPM-PBM-E/Mr. Dybackl 1

USA Materiel Development and Readiness Command

Dover, NJ 07801

Director

US Army Ballistics Research Laboratories

Attn: Safety Office 1

Aberdeen Proving Ground, MD 21005

Director

Defense Research & Engineering 1

Pentagon

Washington, DC 20310

Administrator

Defense Documentation Center

Attn: Accessions Division 2

Cameron Station

Alexandria, VA 22314

Commander

Chemical Systems Laboratory

Attn: DRDAR-CLF 1

DRDAR-CLN 3

Aberdeen Proving Ground, MD 21010

Commander

Aberdeen Proving Ground

Attn: DRSAR-MAS-C 5

Aberdeen Proving Ground, MD 21010

Commander

US Army Armament Readiness Command

Attn: DRSAR-IRC-E/Mr. Khwaja 2

Rock Island, IL 61201

Director

Chemical Systems Laboratory

Attn: DRDAR-CLJ-L 3

Attn: DRDAR-CLJ-R 2

Aberdeen Proving Ground, MD 21010

Commander

US Army Armament Research and Development Command

Attn: DRDAR-TSS 2

Dover, NJ 07801